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Bansal et al.

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(54) **PERFORMING CALL STACK SAMPLING**

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(73) Assignee: **AppDynamics, Inc.**, San Francisco, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(22) Filed: **Nov. 4, 2013**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. 13/189,360, filed on Jul. 22, 2011, now Pat. No. 8,938,533, which is a continuation-in-part of application No. 12/878,919, filed on Sep. 9, 2010.

(60) Provisional application No. 61/241,256, filed on Sep. 10, 2009.

(51) **Int. Cl.**

G06F 15/173	(2006.01)
H04L 12/26	(2006.01)
H04L 29/08	(2006.01)

(52) **U.S. Cl.**

CPC ***H04L 43/04*** (2013.01); ***H04L 43/022*** (2013.01); ***H04L 43/045*** (2013.01); ***H04L 67/22*** (2013.01); ***H04L 67/02*** (2013.01)

(58) **Field of Classification Search**

CPC H04L 67/36; H04L 43/04; H04L 43/08; G06F 11/34; G06F 11/36

USPC 709/200, 224; 717/127; 718/101; 719/317

See application file for complete search history.

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(Continued)

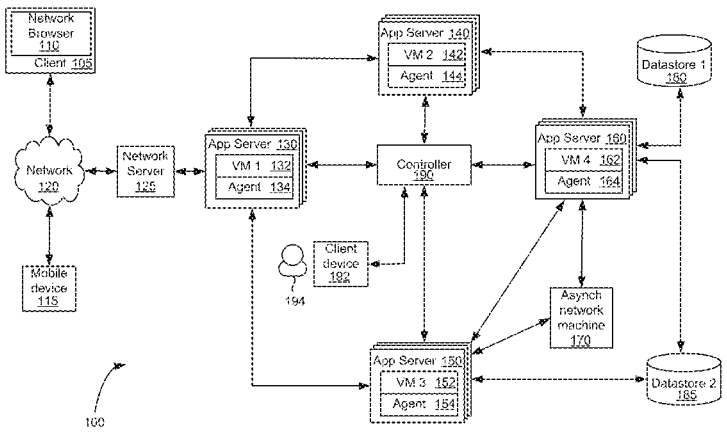
Primary Examiner — Anthony Mejia

(74) *Attorney, Agent, or Firm* — Lewis Roca Rothgerber LLP

(57) **ABSTRACT**

The present technology may determine an anomaly in a portion of a distributed business application. Data can automatically be captured and analyzed for the portion of the application associated with the anomaly. By automatically capturing data for just the portion associated with the anomaly, the present technology reduces the resource and time requirements associated with other code-based solutions for monitoring transactions. A method for sampling an application thread to monitor a request may begin with detecting a diagnostic event with respect to the processing of a request. A thread call stack associated with the request may be sampled in response to detecting the diagnostic event. A state of the call stack may be stored with timing information based on the sampling. The call stack state and timing information may be transmitted to a remote server.

30 Claims, 17 Drawing Sheets



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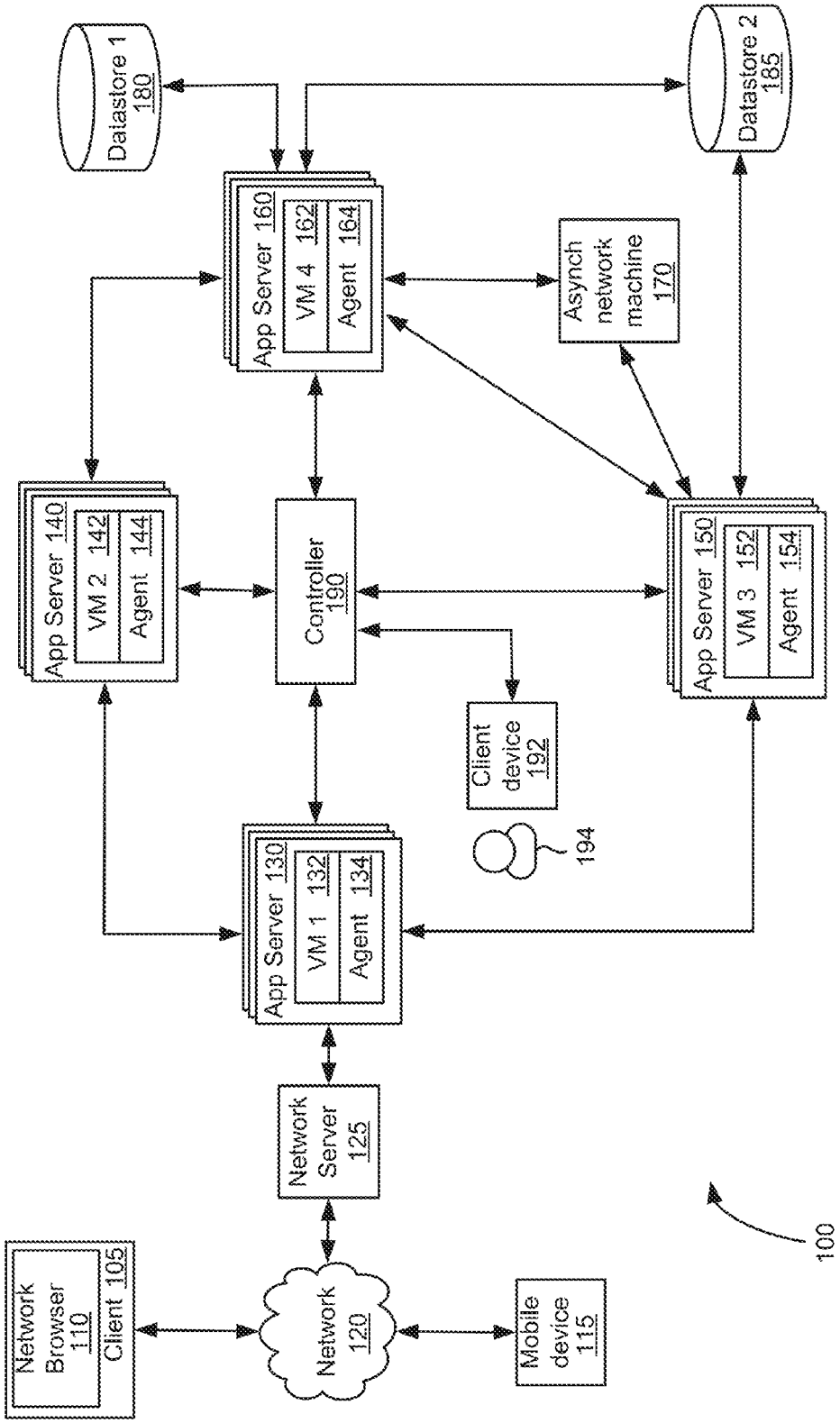
Datastore 1
180
Datastore 2
185
App Server 160
VM 4 162
Agent 164
Asynch network machine
170
App Server 140
VM 2 142
Agent 144
Controller
190
App Server 150
VM 3 152
Agent 154
Client device
192
194
App Server 130
VM 1 132
Agent 134
Network Server
125
Network Browser
110
Client 105
Network
120
Mobile device
115
100

FIGURE 1

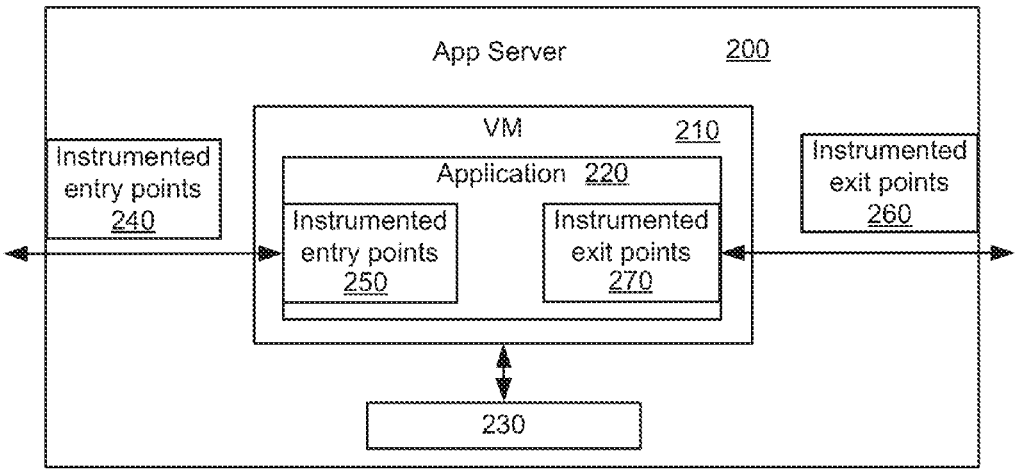
App Server
200
VM
210
Application 220
Instrumented entry points 240
Instrumented entry points 250
Instrumented exit points 270
Instrumented exit points 260
230

FIGURE 2

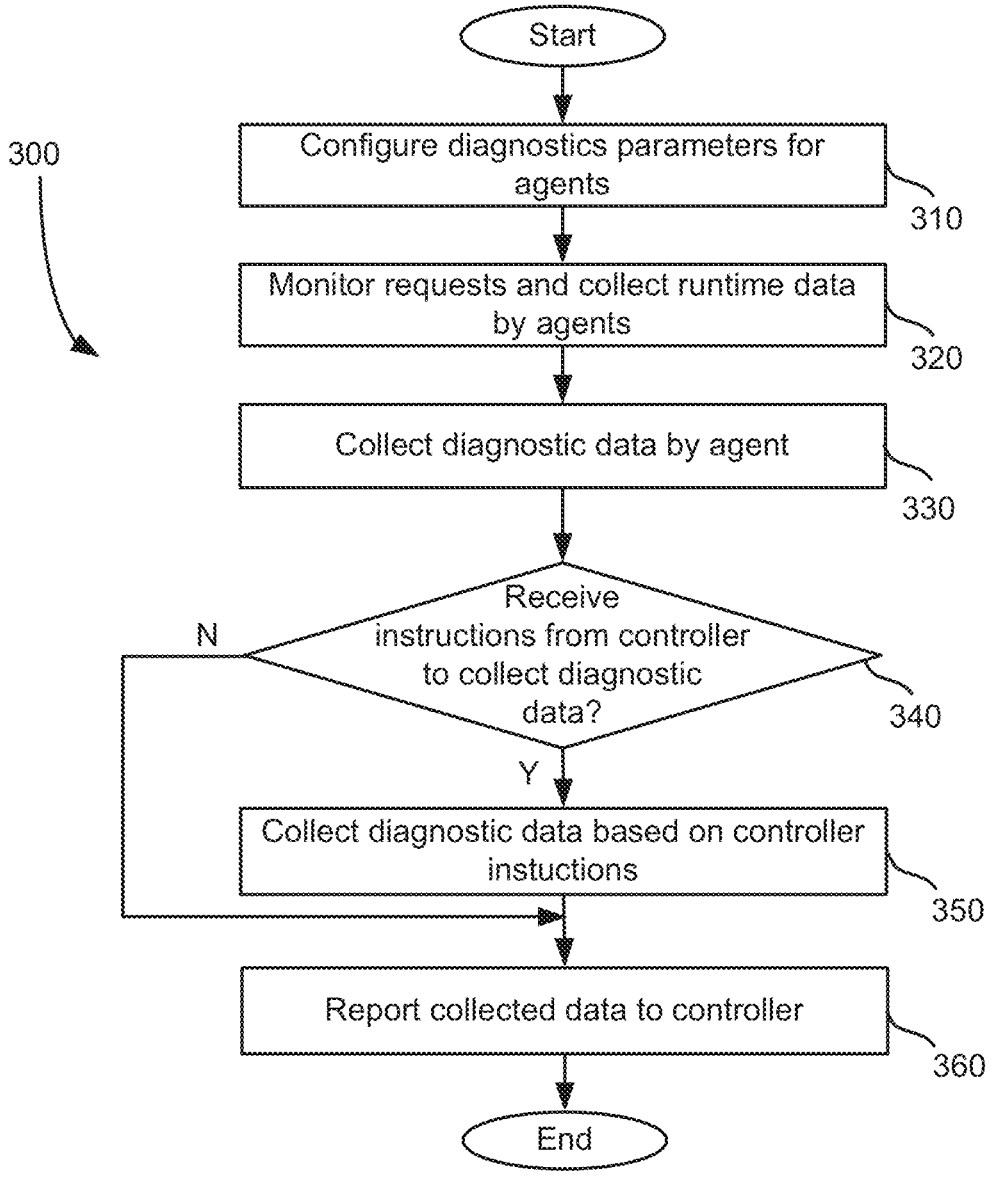
300
Start
Configure diagnostics parameters for agents
310
Monitor requests and collect runtime data by agents
320
Collect diagnostic data by agent
330
Receive instructions from controller to collect diagnostic data?
340
N
Y
Collect diagnostic data based on controller instuctions
350
Report collected data to controller
360
End

FIGURE 3A

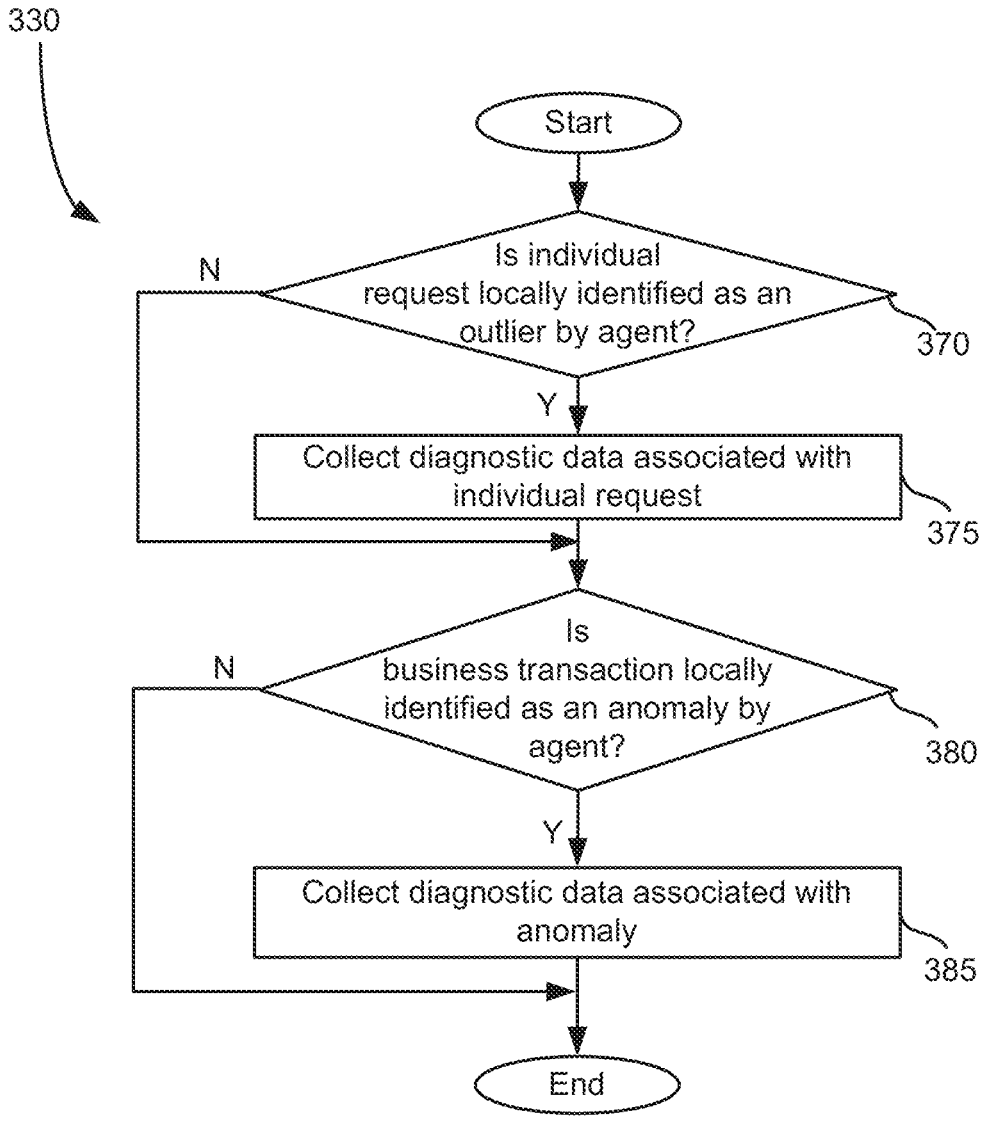
330
Start
Is individual request locally identified as an outlier by agent?
N
Y
370
Collect diagnostic data associated with individual request
375
Is business transaction locally identified as an anomaly by agent?
N
Y
380
Collect diagnostic data associated with anomaly
385
End

FIGURE 3B

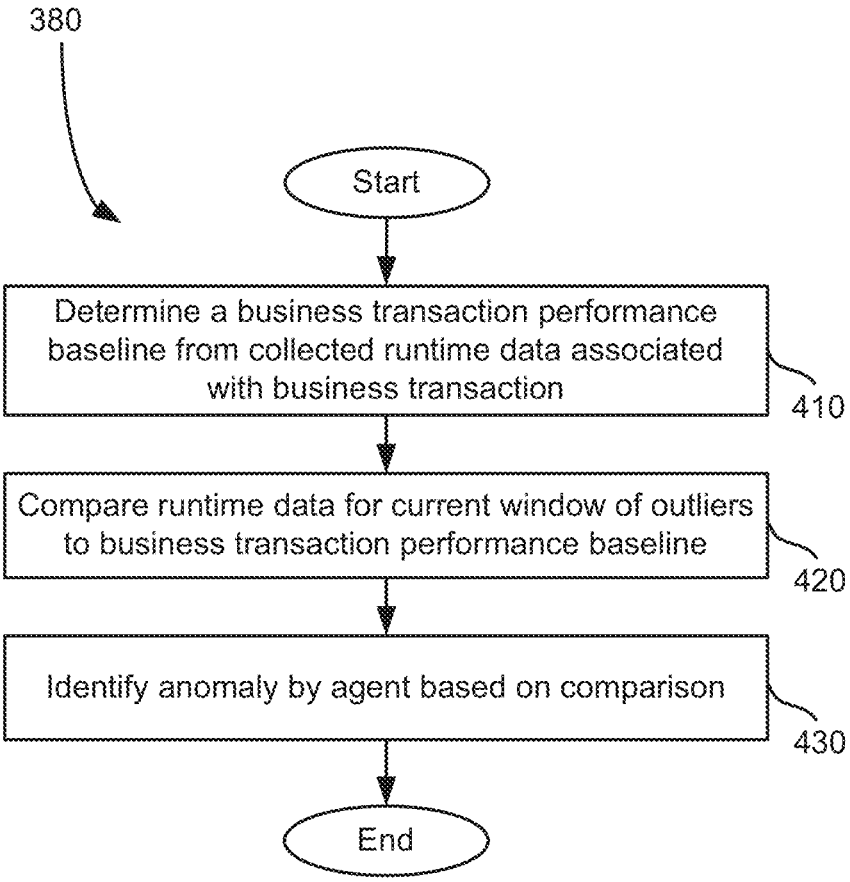
380
Start
Determine a business transaction performance baseline from collected runtime data associated with business transaction
410
Compare runtime data for current window of outliers to business transaction performance baseline
420
Identify anomaly by agent based on comparison
430
End

FIGURE 4

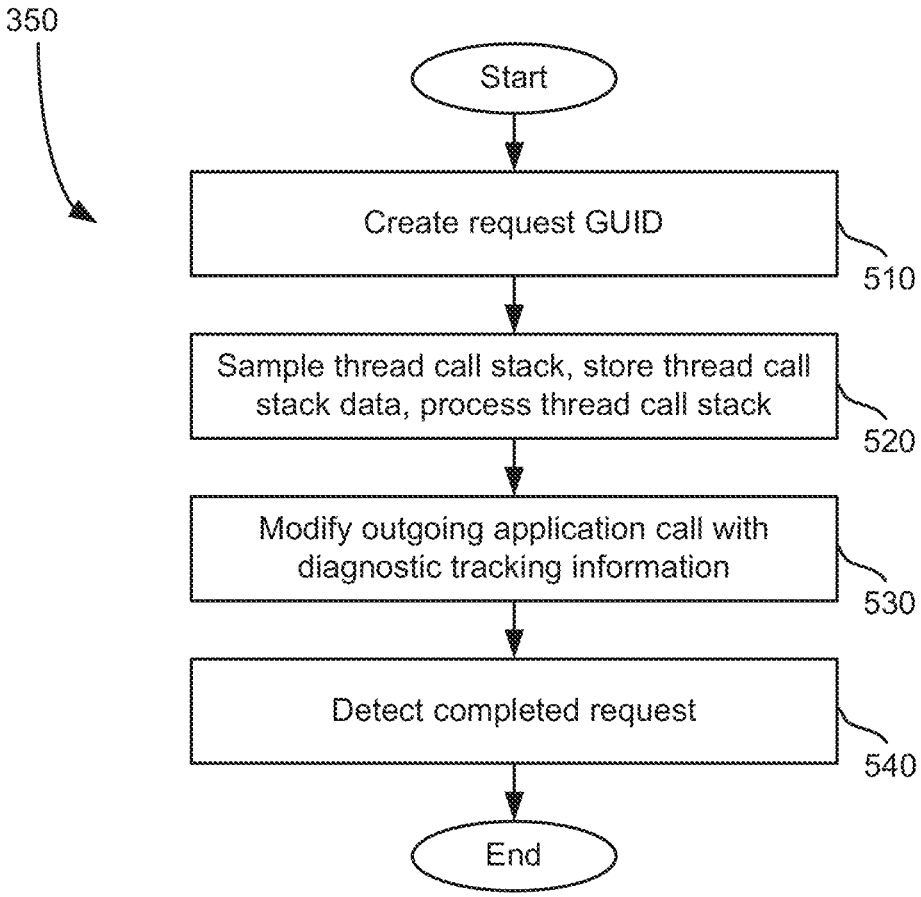
350
Start
Create request GUID
510
Sample thread call stack, store thread call stack data, process thread call stack
520
Modify outgoing application call with diagnostic tracking information
530
Detect completed request
540
End

FIGURE 5

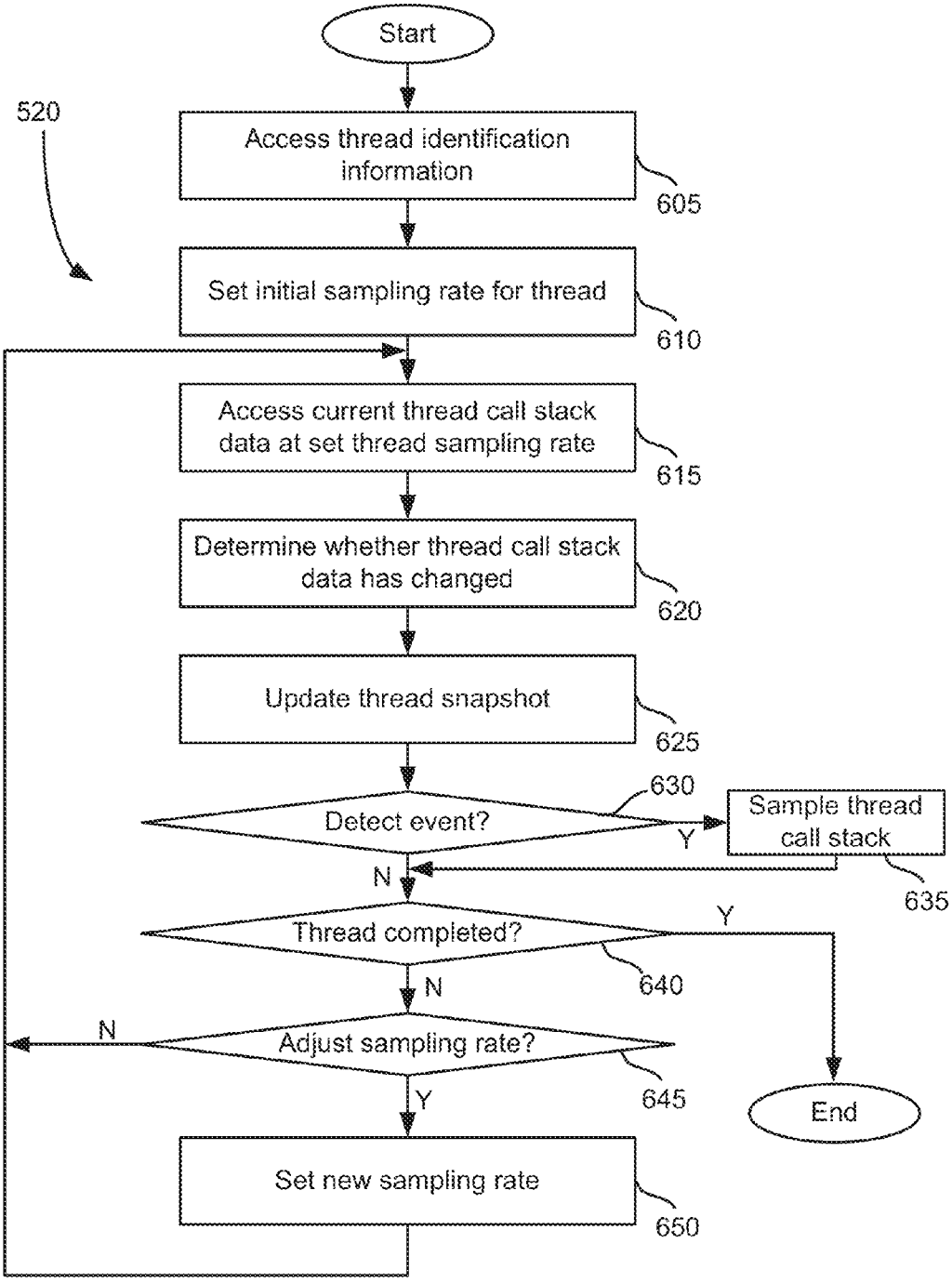
Start
520
Access thread identification information
605
Set initial sampling rate for thread
610
Access current thread call stack data at set thread sampling rate
615
Determine whether thread call stack data has changed
620
Update thread snapshot
625
630
Detect event?
Y
Sample thread call stack
635
N
Thread completed?
Y
640
N
N
Adjust sampling rate?
645
Y
End
Set new sampling rate
650

FIGURE 6A

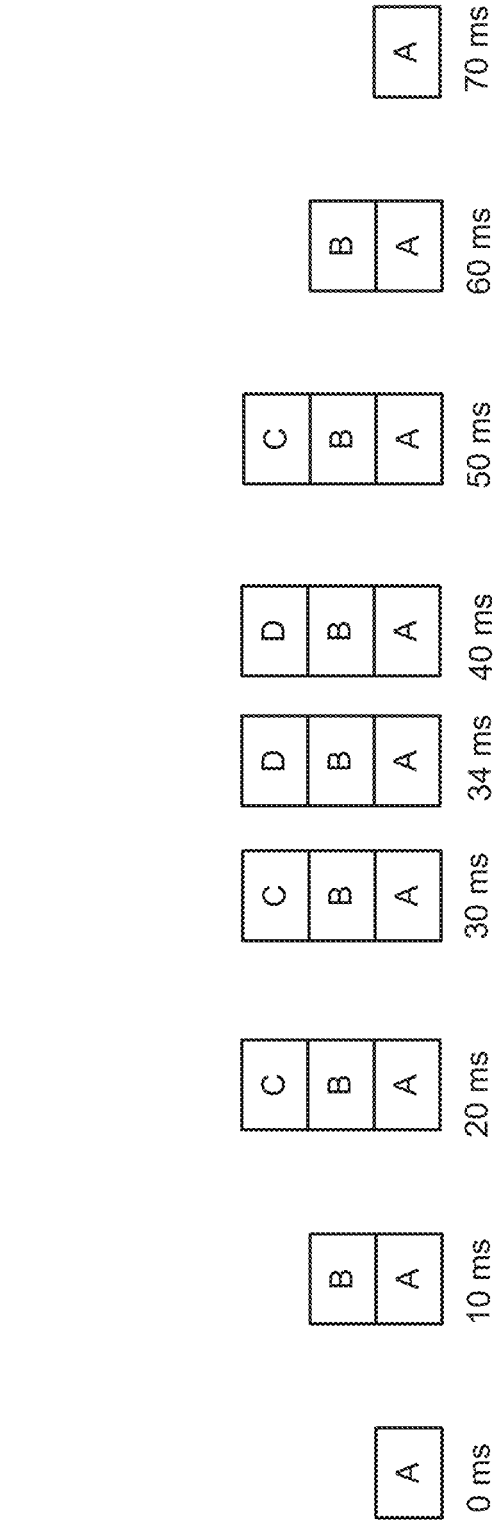
A
0 ms
B
A
10 ms
C
B
A
20 ms
C
B
A
30 ms
D
B
A
34 ms
D
B
A
40 ms
C
B
A
50 ms
B
A
60 ms
A
70 ms

FIGURE 6B

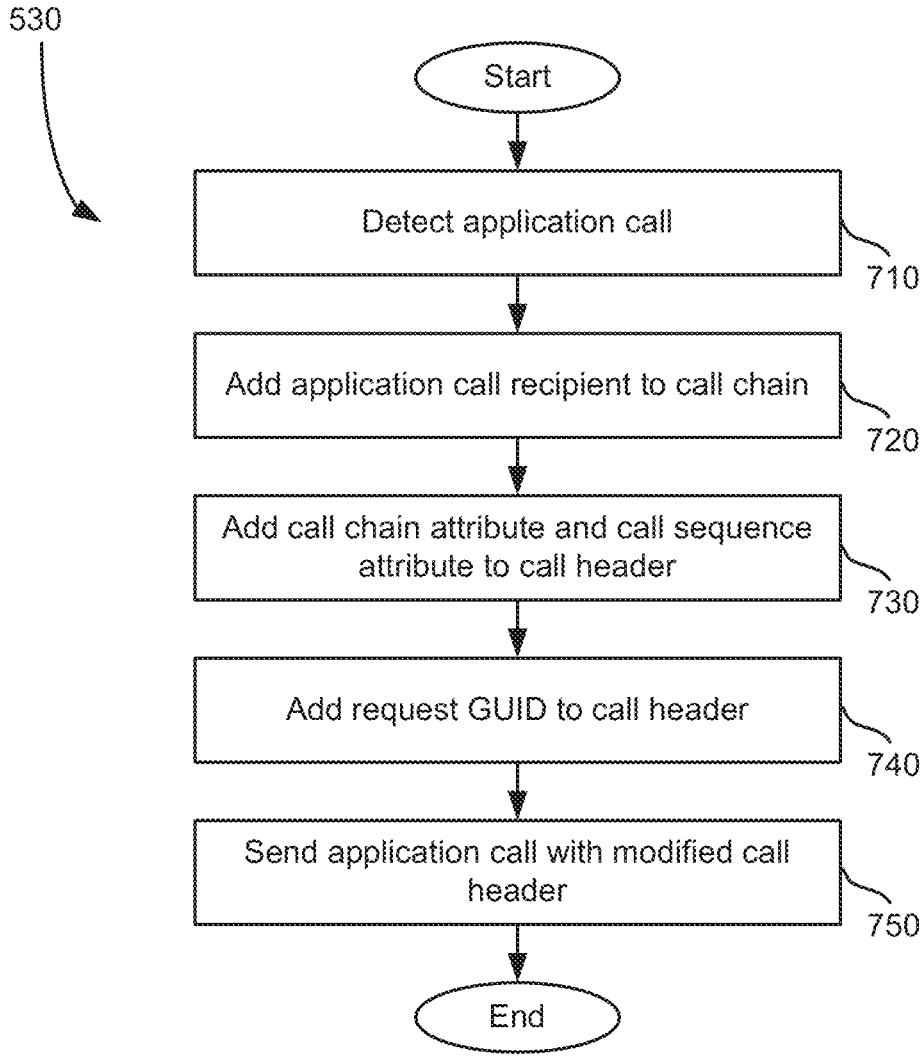
530
Start
Detect application call
710
Add application call recipient to call chain
720
Add call chain attribute and call sequence attribute to call header
730
Add request GUID to call header
740
Send application call with modified call header
750
End

FIGURE 7

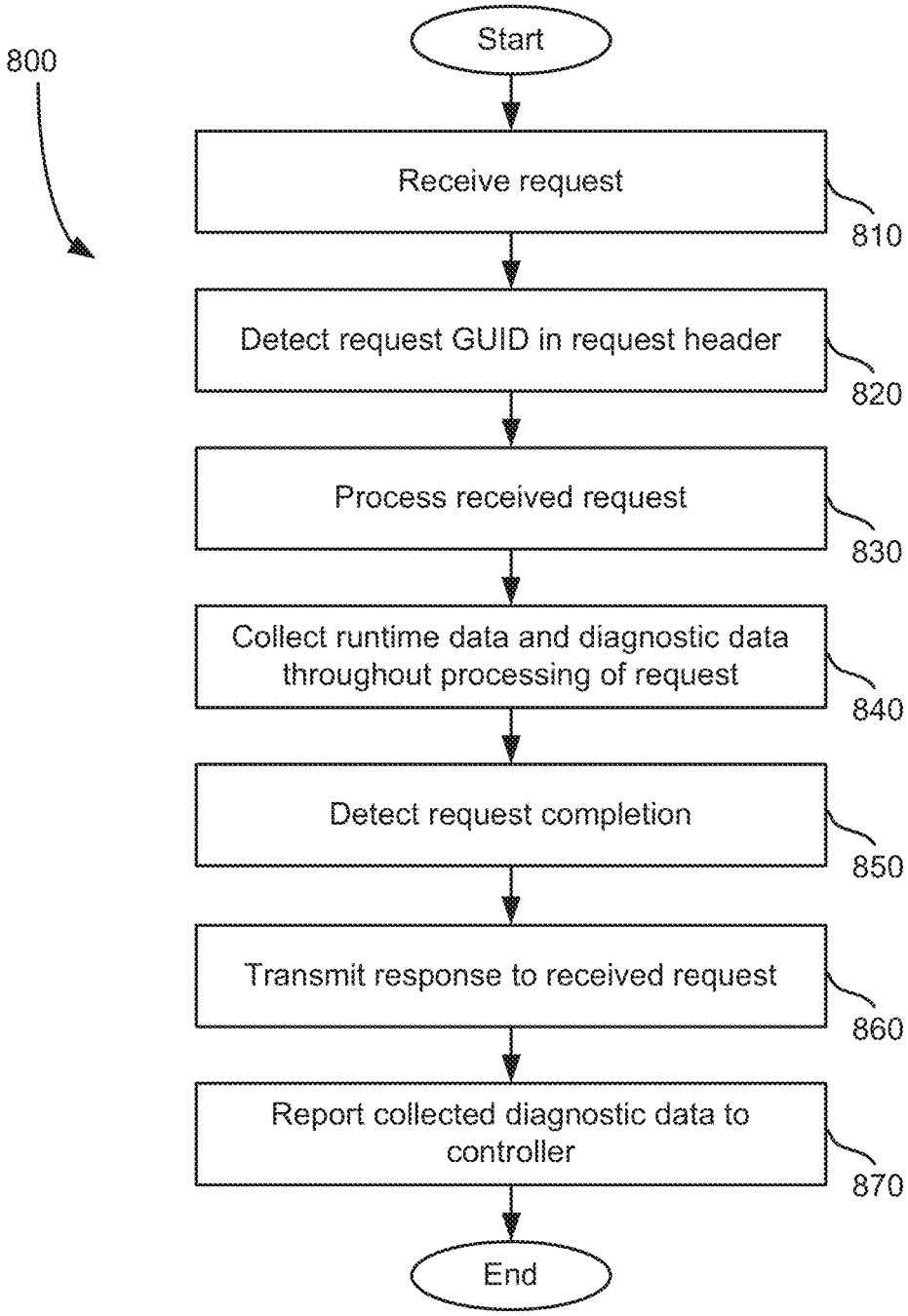
800
Start
Receive request
810
Detect request GUID in request header
820
Process received request
830
Collect runtime data and diagnostic data throughout processing of request
840
Detect request completion
850
Transmit response to received request
860
Report collected diagnostic data to controller
870
End

FIGURE 8

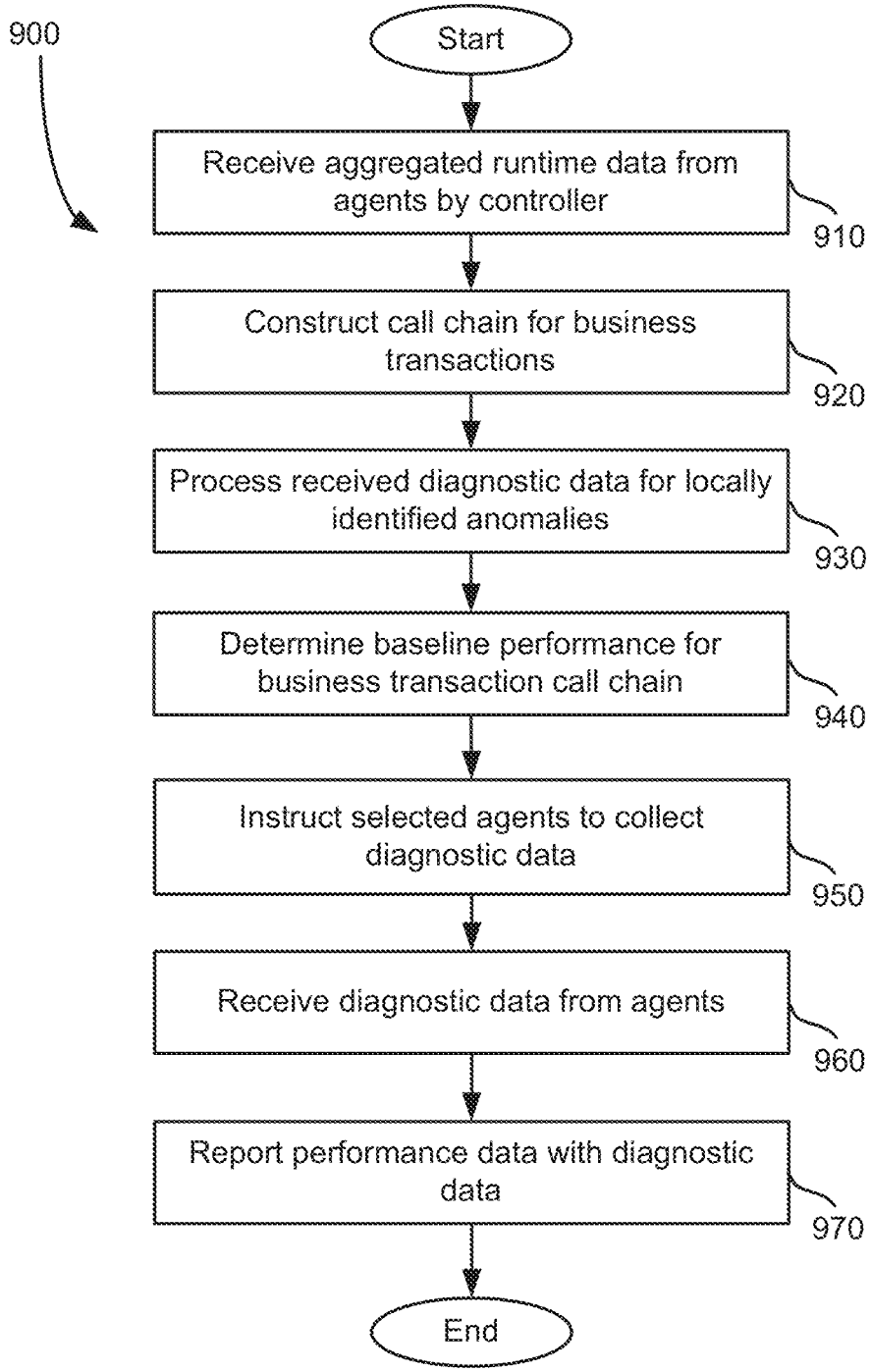
900
Start
Receive aggregated runtime data from agents by controller
910
Construct call chain for business transactions
920
Process received diagnostic data for locally identified anomalies
930
Determine baseline performance for business transaction call chain
940
Instruct selected agents to collect diagnostic data
950
Receive diagnostic data from agents
960
Report performance data with diagnostic data
970
End

FIGURE 9A

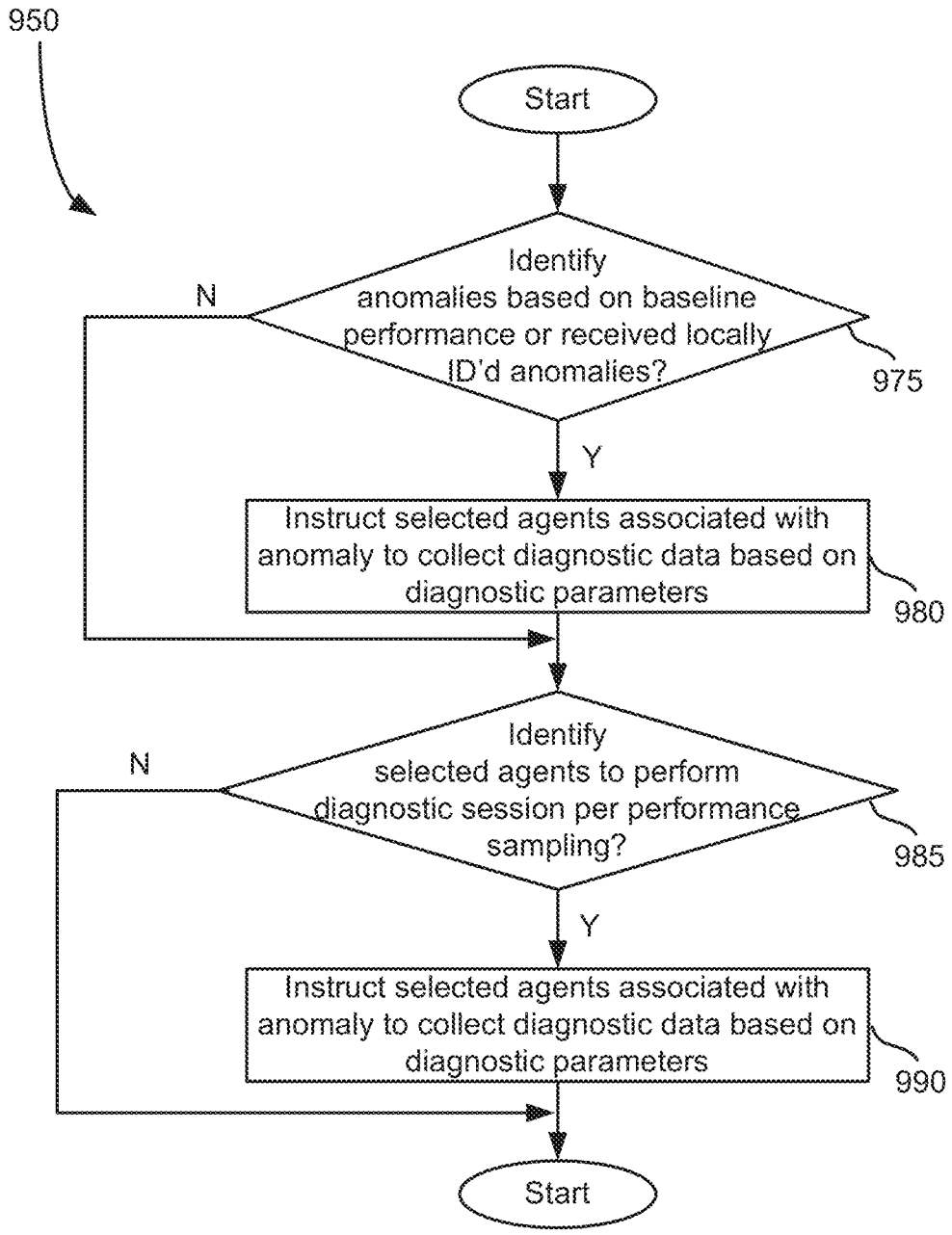
950
Start
Identify anomalies based on baseline performance or received locally ID'd anomalies?
N
975
Y
Instruct selected agents associated with anomaly to collect diagnostic data based on diagnostic parameters
980
Identify selected agents to perform diagnostic session per performance sampling?
N
985
Y
Instruct selected agents associated with anomaly to collect diagnostic data based on diagnostic parameters
990
Start

FIGURE 9B

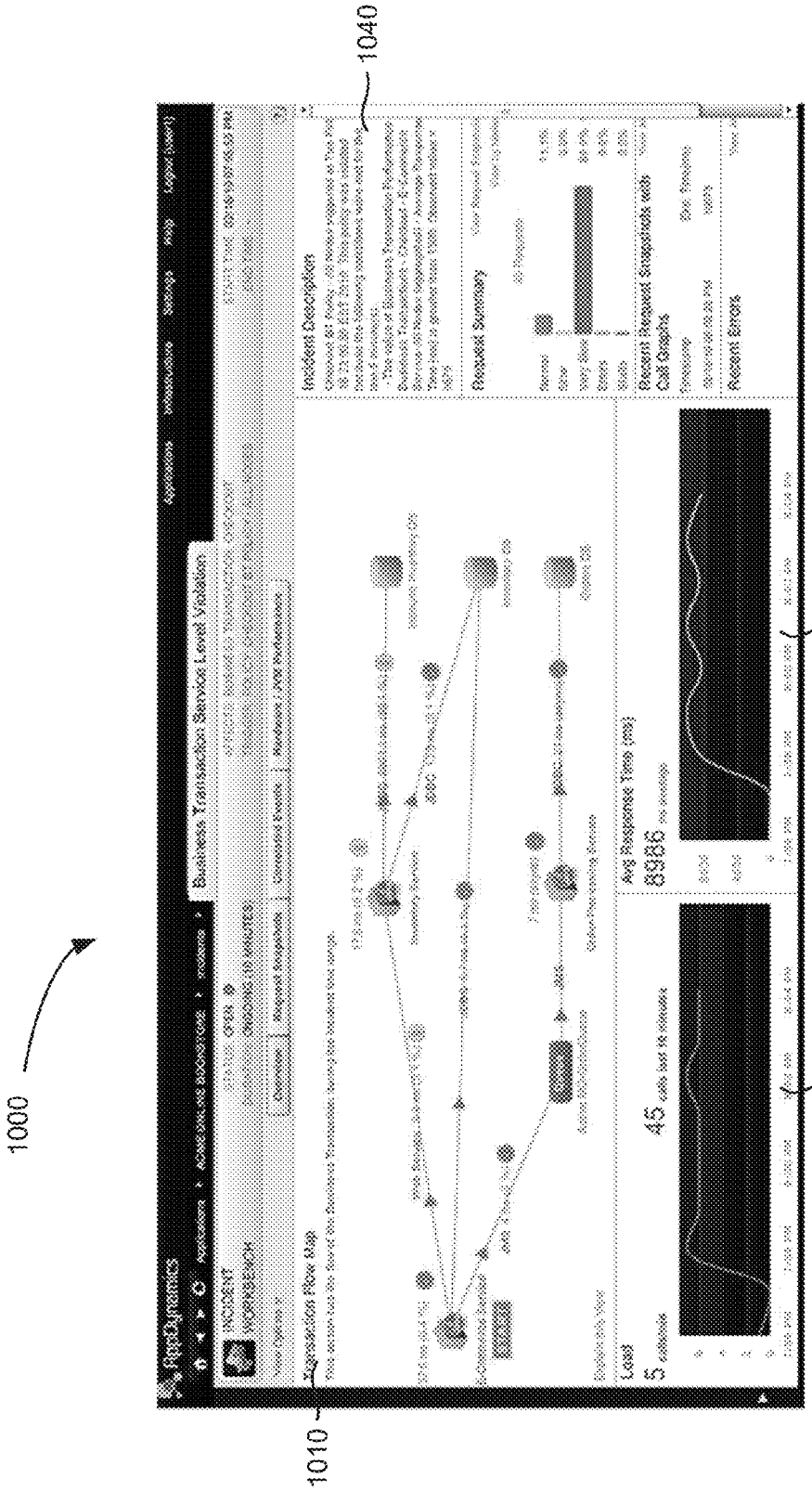
1000
1010
1020
1030
1040
AppDynamics
Business Transaction Service Level Violation
Application Flow Map
Incident Description
Request Summary
Recent Request Snapshots with Call Graphs
Recent Errors
Load
45
Avg Response Time (ms)
8986

FIGURE 10

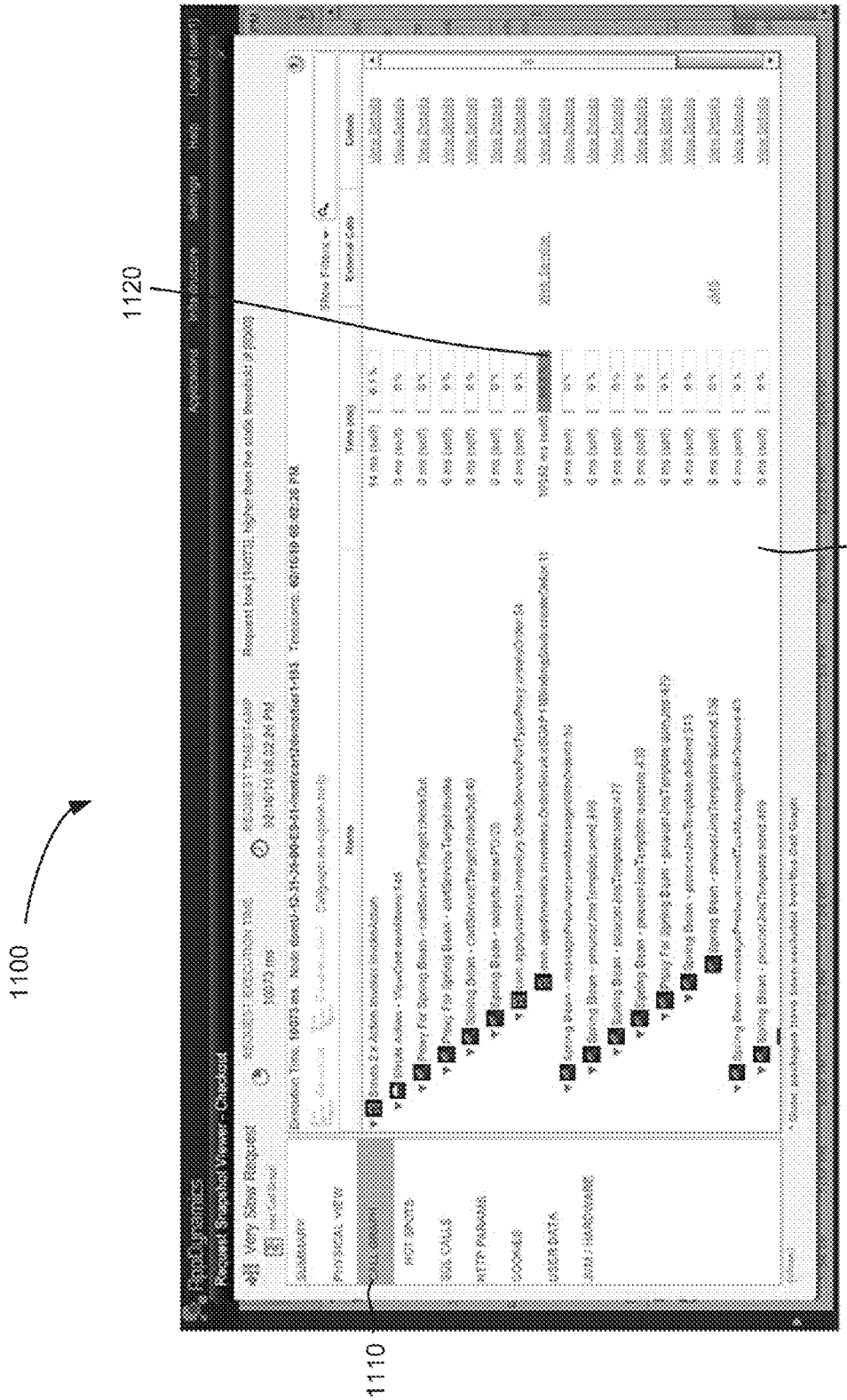

FIGURE 11A

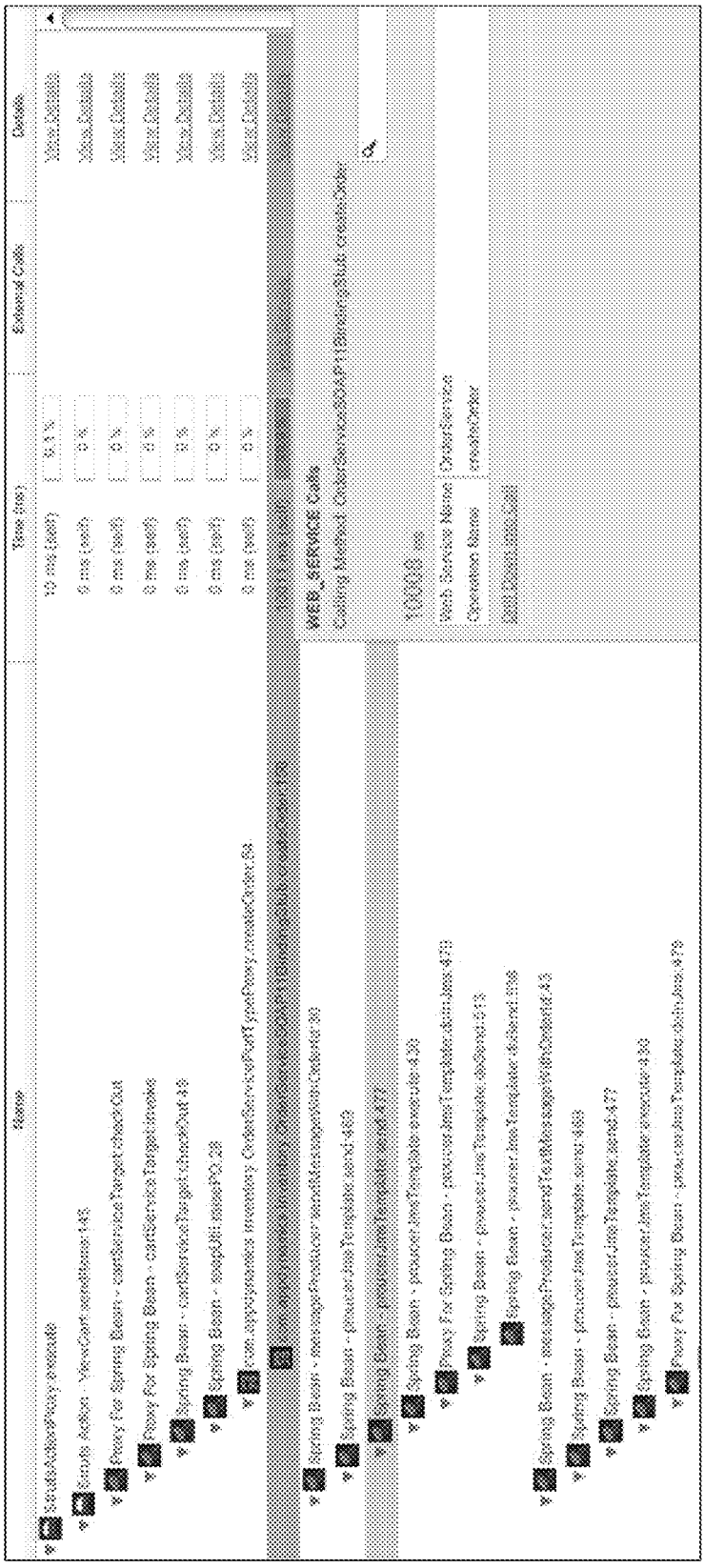
Name
Time (ms)
External Calls
Details
WEB_SERVICE Calls
Web Service Name
Operation Name

FIGURE 11B

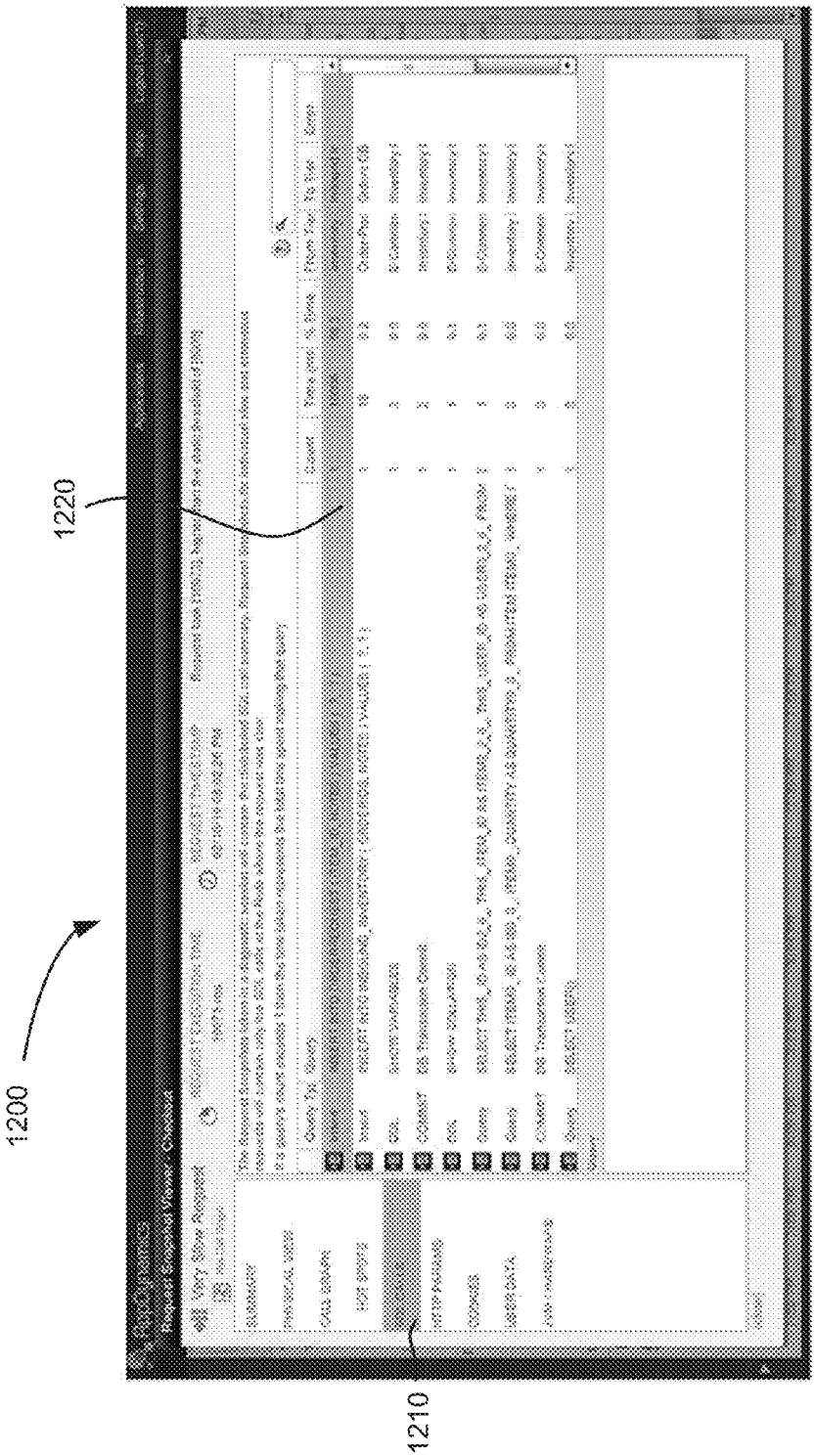

FIGURE 12

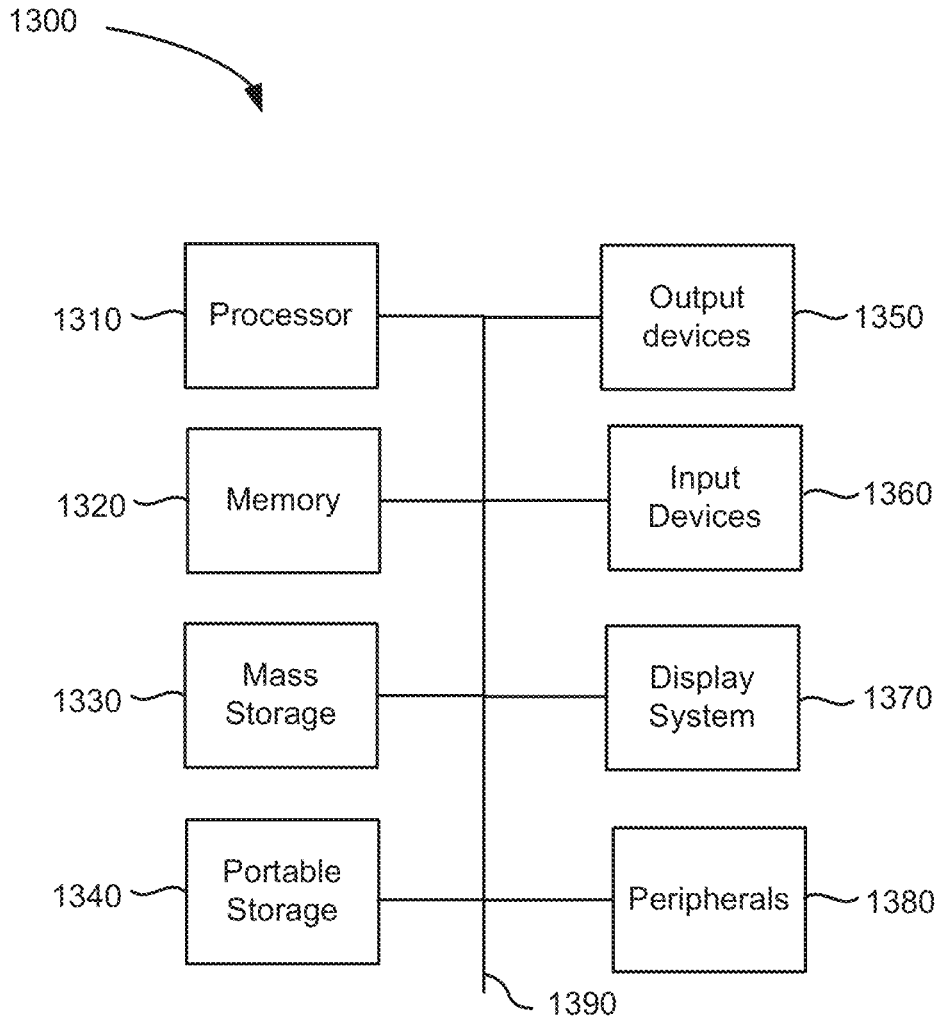
1300
1310
Processor
1320
Memory
1330
Mass Storage
1340
Portable Storage
Output devices
1350
Input Devices
1360
Display System
1370
Peripherals
1380
1390

Figure 13

PERFORMING CALL STACK SAMPLING

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation and claims the priority benefit of U.S. patent application Ser. No. 13/189,360, titled "Automatic Capture of Diagnostic Data Based on Transaction Behavior Learning," filed Jul. 22, 2011, which is a continuation-in-part and claims the priority benefit of U.S. patent application Ser. No. 12/878,919, titled "Monitoring Distributed Web Application Transactions," filed Sep. 9, 2010, which claims the priority benefit of U.S. Provisional Application Ser. No. 61/241,256, titled "Automated Monitoring of Business Transactions," filed Sep. 10, 2009, the disclosure of which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

The World Wide Web has expanded to provide web services faster to consumers. Web services may be provided by a web application which uses one or more services to handle a transaction. The applications may be distributed over several machines, making the topology of the machines that provides the service more difficult to track and monitor.

Monitoring a web application helps to provide insight regarding bottle necks in communication, communication failures and other information regarding performance of the services the provide the web application. When a web application is distributed over several machines, tracking the performance of the web service can become impractical with large amounts of data collected from each machine.

When a distributed web application is not operating as expected, additional information regarding application performance can be used to evaluate the health of the application. Collecting the additional information can consume large amounts of resources and often requires significant time to determine how to collect the information.

There is a need in the art for web service monitoring which may accurately and efficiently monitor the performance of distributed applications which provide a web service.

SUMMARY OF THE CLAIMED INVENTION

The present technology monitors a distributed network application system and may detect an anomaly based the learned behavior of the system. The behavior may be learned for each of one or more machines which implement a distributed business transaction. The present system may automatically collect diagnostic data for one or more business transactions and/or requests based on learned behavior for the business transaction or request. The diagnostic data may include detailed data for the operation of the distributed web application and be processed to identify performance issues for a transaction. Detailed data for a distributed web application transaction may be collected by sampling one or more threads assigned to handle portions of the distributed business transaction. Data regarding the distributed transaction may then be reported from agents monitoring portions of the distributed transaction to one or more central controllers and assembled by one or more controllers into business transactions. Data associated with one or more anomalies may be reported via one or more user interfaces.

Collection of diagnostic data at a server may be initiated locally by an agent or remotely from a controller. An agent may initiate collection of diagnostic data based on a monitored individual request or a history of monitored requests

associated with a business transaction. For example, an agent at an application or Java Virtual Machine (JVM) may trigger the collection of diagnostic runtime data for a particular request if the request is characterized as an outlier. The agent may also trigger a diagnostic session for a business transaction or other category of request if the performance of requests associated with the business transaction varies from a learned baseline performance for the business transaction. The agent may determine baselines for request performance and compare the runtime data to the baselines to identify the anomaly. A controller may receive aggregated runtime data reported by the agents, process the runtime data, and determine an anomaly based on the processed runtime data that doesn't satisfy one or more parameters, thresholds or baselines.

In an embodiment, a method for sampling an application thread to monitor a request begins with detecting a diagnostic event with respect to the processing of a request. A thread call stack associated with the request may be sampled in response to detecting the diagnostic event. A state of the call stack may be stored with timing information based on the sampling. The call stack state and timing information may be transmitted to a remote server.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a block diagram of an exemplary system for monitoring a distributed application.

FIG. **2** is a block diagram of an exemplary application server.

FIG. **3**A is a flow chart of an exemplary method for performing a diagnostic session for a distributed web application transaction.

FIG. **3**B is a flow chart of an exemplary method for collecting diagnostic data.

FIG. **4** is a flow chart of a method for locally identifying an anomaly.

FIG. **5** is a flow chart of an exemplary method for collecting diagnostic data.

FIG. **6**A is a flow chart of an exemplary method for sampling a thread.

FIG. **6**B is an illustration of an exemplary thread call stack data over time.

FIG. **7** is a flow chart of an exemplary method for modifying an application call.

FIG. **8** is a flow chart of an exemplary method for processing a received request.

FIG. **9**A is a flow chart of an exemplary method for controller operation.

FIG. **9**B is a flow chart of an exemplary method for instructing agents by a controller.

FIG. **10** is an exemplary interface providing a transaction flow map.

FIG. **11**A is an exemplary interface for providing a call graph.

FIG. **11**B is an exemplary interface for providing more information for selected call within a call graph.

FIG. **12** is an exemplary interface for providing SQL call information.

FIG. **13** is a block diagram of an exemplary system for implementing a computing device.

DETAILED DESCRIPTION

The present technology monitors a network or web application provided by one or more distributed applications. The web application may be provided by one or more web ser-

vices each implemented as a virtual machine or one or more applications implemented on a virtual machine. Agents may be installed on one or more servers at an application level, virtual machine level, or other level. An agent may monitor a corresponding application (or virtual machine) and application communications. Each agent may communicate with a controller and provide monitoring data to the controller. The controller may process the data to learn and evaluate the performance of the application or virtual machine, model the flow of the application, and determine information regarding the distributed web application performance. The monitoring technology determines how each distributed web application portion is operating, establishes a baseline for operation, and determines the architecture of the distributed system.

The present technology may monitor a distributed web application that performs one or more business transactions. A business transaction may be a set of tasks performed by one or more distributed web applications in the course of a service provide over a network. In an e-commerce service, a business transaction may be "add to cart" or "check-out" transactions performed by the distributed application.

The behavior of a system which implements a distributed web transaction may be learned for each of one or more machines which implement the distributed transaction. The behavior may be learned for a business transaction which includes multiple requests and a particular request. The present system may automatically collect diagnostic data for one or more business transactions and/or requests based on learned behavior of the business transaction or request. The diagnostic data may include detailed data for the operation of the distributed web application and be processed to identify performance issues for a transaction. Detailed data for a distributed web application transaction may be collected by sampling one or more threads assigned to handle portions of the distributed business transaction. Data regarding the distributed transaction may then be reported from agents monitoring portions of the distributed transaction to one or more central controllers and assembled by one or more controllers into business transactions. Data associated with one or more anomalies may be reported via one or more user interfaces.

The present technology may perform a diagnostic session for an anomaly detected in the performance of a portion of a distributed web application, such as a business transaction or category of request. During the diagnostic session, detailed data may be collected for the operation of the distributed web application. The data may be processed to identify performance issues for a transaction. Detailed data for a distributed web application transaction may be collected by sampling one or more threads assigned to handle portions of the distributed business transaction. Data regarding the distributed transaction may be reported from one or more agents at an application or Java Virtual Machine (JVM) to one or more controllers. The data may be received and assembled by the one or more controllers into business transactions.

The monitoring system may monitor distributed web applications across a variety of infrastructures. The system is easy to deploy and provides end-to-end business transaction visibility. The monitoring system may identify performance issues quickly and has a dynamical scaling capability across a monitored system. The present monitoring technology has a low footprint and may be used with cloud systems, virtual systems and physical infrastructures.

Agents may communicate with code within virtual machine or an application. The code may detect when an application entry point is called and when an application exit point is called. An application entry point may include a call received by the application. An application exit point may include a call made by the application to another application, virtual machine, server, or some other entity. The code within the application may insert information into an outgoing call or request (exit point) and detect information contained in a received call or request (entry point). By monitoring incoming and outgoing calls and requests, and by monitoring the performance of a local application that processes the incoming and outgoing request, the present technology may determine the performance and structure of complicated and distributed business transactions.

FIG. **1** is a block diagram of an exemplary system for monitoring a distributed web application. The system of FIG. **1** may be used to implement a distributed web application and detect anomalies in the performance of the distributed web application. System **100** of FIG. **1** includes client device **105**, mobile device **115**, network **120**, network server **125**, application servers **130**, **140**, **150** and **160**, asynchronous network machine **170**, data stores **180** and **185**, and controller **190**.

Client device **105** may include network browser **110** and be implemented as a computing device, such as for example a laptop, desktop, workstation, or some other computing device. Network browser **110** may be a client application for viewing content provided by an application server, such as application server **130** via network server **125** over network **120**. Mobile device **115** is connected to network **120** and may be implemented as a portable device suitable for receiving content over a network, such as for example a mobile phone, smart phone, or other portable device. Both client device **105** and mobile device **115** may include hardware and/or software configured to access a web service provided by network server **125**.

Network **120** may facilitate communication of data between different servers, devices and machines. The network may be implemented as a private network, public network, intranet, the Internet, or a combination of these networks.

Network server **125** is connected to network **120** and may receive and process requests received over network **120**. Network server **125** may be implemented as one or more servers implementing a network service. When network **120** is the Internet, network server **125** maybe implemented as a web server.

Application server **130** communicates with network server **125**, application servers **140** and **150**, controller **190**. Application server **130** may also communicate with other machines and devices (not illustrated in FIG. **1**). Application server **130** may host an application or portions of a distributed application and include a virtual machine **132**, agent **134**, and other software modules. Application server **130** may be implemented as one server or multiple servers as illustrated in FIG. **1**.

Virtual machine **132** may be implemented by code running on one or more application servers. The code may implement computer programs, modules and data structures to implement a virtual machine mode for executing programs and applications. In some embodiments, more than one virtual machine **132** may execute on an application server **130**. A virtual machine may be implemented as a Java Virtual Machine (JVM). Virtual machine **132** may perform all or a portion of a business transaction performed by application servers comprising system **100**. A virtual machine may be considered one of several services that implement a web service.

Virtual machine **132** may be instrumented using byte code insertion, or byte code instrumentation, to modify the object code of the virtual machine. The instrumented object code may include code used to detect calls received by virtual

machine **132**, calls sent by virtual machine **132**, and communicate with agent **134** during execution of an application on virtual machine **132**. Alternatively, other code may be byte code instrumented, such as code comprising an application which executes within virtual machine **132** or an application which may be executed on application server **130** and outside virtual machine **132**.

Agent **134** on application server **130** may be installed on application server **130** by instrumentation of object code, downloading the application to the server, or in some other manner. Agent **134** may be executed to monitor application server **130**, monitor virtual machine **132**, and communicate with byte instrumented code on application server **130**, virtual machine **132** or another application on application server **130**. Agent **134** may detect operations such as receiving calls and sending requests by application server **130** and virtual machine **132**. Agent **134** may receive data from instrumented code of the virtual machine **132**, process the data and transmit the data to controller **190**. Agent **134** may perform other operations related to monitoring virtual machine **132** and application server **130** as discussed herein. For example, agent **134** may identify other applications, share business transaction data, aggregate detected runtime data, and other operations.

Each of application servers **140**, **150** and **160** may include an application and an agent. Each application may run on the corresponding application server or a virtual machine. Each of virtual machines **142**, **152** and **162** on application servers **140-160** may operate similarly to virtual machine **132** and host one or more applications which perform at lease a portion of a distributed business transaction. Agents **144**, **154** and **164** may monitor the virtual machines **142-162**, collect and process data at runtime of the virtual machines, and communicate with controller **190**. The virtual machines **132**, **142**, **152** and **162** may communicate with each other as part of performing a distributed transaction. In particular each virtual machine may call any application or method of another virtual machine.

Controller **190** may control and manage monitoring of business transactions distributed over application servers **130-160**. Controller **190** may receive runtime data from each of agents **134-164**, associate portions of business transaction data, communicate with agents to configure collection of runtime data, and provide performance data and reporting through an interface. The interface may be viewed as a web-based interface viewable by mobile device **115**, client device **105**, or some other device. In some embodiments, a client device **192** may directly communicate with controller **190** to view an interface for monitoring data.

Asynchronous network machine **170** may engage in asynchronous communications with one or more application servers, such as application server **150** and **160**. For example, application server **150** may transmit several calls or messages to an asynchronous network machine. Rather than communicate back to application server **150**, the asynchronous network machine may process the messages and eventually provide a response, such as a processed message, to application server **160**. Because there is no return message from the asynchronous network machine to application server **150**, the communications between them are asynchronous.

Data stores **180** and **185** may each be accessed by application servers such as application server **150**. Data store **185** may also be accessed by application server **150**. Each of data stores **180** and **185** may store data, process data, and return queries received from an application server. Each of data stores **180** and **185** may or may not include an agent.

FIG. **2** is a block diagram of an exemplary application server **200**. The application server in FIG. **2** provides more information for each application server of system **100** in FIG. **1**. Application server **200** of FIG. **2** includes a virtual machine **210**, application **220** executing on the virtual machine, and agent **230**. Virtual machine **210** may be implemented by programs and/or hardware. For example, virtual machine **134** may be implemented as a JAVA virtual machine. Application **220** may execute on virtual machine **210** and may implement at least a portion of a distributed application performed by application servers **130-160**. Application server **200**, virtual machine **210** and agent **230** may be used to implement any application server, virtual machine and agent of a system such as that illustrated in FIG. **1**.

Application server **200** and application **220** can be instrumented via byte code instrumentation at exit and entry points. An entry point may be a method or module that accepts a call to application **220**, virtual machine **210**, or application server **200**. An exit point is a module or program that makes a call to another application or application server. As illustrated in FIG. **2**, an application server **200** can have byte code instrumented entry points **240** and byte code instrumented exit points **260**. Similarly, an application **220** can have byte code instrumentation entry points **250** and byte code instrumentation exit points **270**. For example, the exit points may include calls to JDBC, JMS, HTTP, SOAP, and RMI. Instrumented entry points may receive calls associated with these protocols as well.

Agent **230** may be one or more programs that receive information from an entry point or exit point. Agent **230** may process the received information, may retrieve, modify and remove information associated with a thread, may access, retrieve and modify information for a sent or received call, and may communicate with a controller **190**. Agent **230** may be implemented outside virtual machine **210**, within virtual machine **210**, and within application **220**, or a combination of these.

FIG. **3**A is a flow chart of an exemplary method for performing a diagnostic session for a distributed web application transaction. The method of FIG. **3** may be performed for a web transaction that is performed over a distributed system, such as the system of FIG. **1**.

Diagnostic parameters may be configured for one or more agents at step **310**. The diagnostic parameters may be used to implement a diagnostic session conducted for a distributed web application business transaction. The parameters may be set by a user, an administrator, may be pre-set, or may be permanently configured.

Examples of diagnostic parameters that may be configured include the number of transactions to simultaneously track using diagnostic sessions, the number of transactions tracked per time period (e.g., transactions tracked per minute), the time of a diagnostic session, a sampling rate for a thread, a threshold percent of requests detected to run slow before triggering an anomaly, outlier information, and other data. The number of transactions to simultaneously track using diagnostic sessions may indicate the number of diagnostic sessions that may be ongoing at any one time. For example, a parameter may indicate that only 10 different diagnostic sessions can be performed at any one time. The time of a diagnostic session may indicate the time for which a diagnostic session will collect detailed data for operation of a transaction, such as for example, five minutes. The sampling rate of a thread may be automatically set to a sampling rate to collect data from a thread call stack based on a detected change in value of the thread, may be manually configured, or otherwise set. The threshold percent of requests detected to run slow

before triggering an anomaly may indicate a number of requests to be detected that run at less than a baseline threshold before triggering a diagnostic session. Diagnostic parameters may be set at either a controller level or an individual agent level, and may affect diagnostic tracking operation at both a controller and/or an agent.

Requests may be monitored and runtime data may be collected at step **320**. As requests are received by an application and/or JVM, the requests are associated with a business transaction by an agent residing on the application or JVM, and may be assigned a thread within a thread pool by the application or JVM itself. The business transaction is associated with the thread by adding business transaction information, such as a business transaction identifier, to the thread by an agent associated with the application or JVM that receives the request. The thread may be configured with additional monitoring parameter information associated with a business transaction. Monitoring information may be passed on to subsequent called applications and JVMs that perform portions of the distributed transaction as the request is monitored by the present technology.

Diagnostic data is collected by an agent at step **330**. Diagnostic data may be collected for one or more transactions or requests. Diagnostic data may be collected based on the occurrence of an outlier or an anomaly. Collecting diagnostic data is discussed in more detail below with respect to FIG. **3**B.

A determination is made as to whether instructions have been received from a controller to collect diagnostic data at step **340**. A diagnostic session may be triggered "centrally" by a controller based on runtime data received by the controller from one or more agents located throughout a distributed system being monitored. If a controller determines that an anomaly is associated with a business transaction, or portion of a business transaction for which data has been reported to the controller, the controller may trigger a diagnostic session and instruct one or more agents residing on applications or JVMs that handle the business transaction to conduct a diagnostic session for the distributed business transaction. Operation of a controller is discussed in more detail below with respect to the method of FIG. **9**A.

If no instructions are received from a controller to collect diagnostic data, the method of FIG. **3** continues to step **360**. If instructions are received from a controller to collect diagnostic data, diagnostic data is collected based on the controller instructions at step **350**. An agent receiving the instructions may collect data for the remainder of the current instance of a distributed application as well as subsequent instances of the request. Collecting diagnostic data based on instructions received by a controller is described below with respect to the method of FIG. **5**. Next, data collected by a particular agent is reported to a controller at step **360**. Each agent in a distributed system may aggregate collected data and send data to a controller. The data may include business transaction name information, call chain information, the sequence of a distributed transaction, and other data, including diagnostic data collected as part of a diagnostic session involving one or more agents.

FIG. **3**B is a flow chart of an exemplary method for collecting diagnostic data. The method of FIG. **3**B provides more detail for step **330** of the method of FIG. **3**A. A determination is made as to whether an individual request is locally identified as an outlier by an agent at step **370**. The identification may be determined based on runtime data collected for the particular request. An outlier may be identified as a request having a characteristic that satisfies a certain threshold. For example, an outlier may have a response time, or time of completion, that is greater than a threshold used to identify outliers. The threshold may be determined based on an average and a standard deviation for the request characteristic. For example, the average time for a request to complete may be 200 milliseconds, and the standard deviation may be 20 milliseconds. A request having a duration within the standard deviation of the average may be considered normal, a request outside the standard deviation but within a range of twice the standard deviation may be considered slow, and a request having a duration outside twice the standard deviation from the average may be considered an outlier.

If the request is locally identified locally as an outlier at step **370**, a diagnostic data (i.e., detailed data regarding the request) associated with the particular request associated with the outlier is collected at step **375**. Diagnostic data may be collected by sampling a thread call stack for the thread that is locally handling the request associated with the outlier. The agent may collect data for the remainder of the request duration. After collecting diagnostic data, the method of FIG. **3**B continues to step **380**. If the request is not identified locally as an anomaly, the method of FIG. **3** continues at step **380**.

A determination is made as to whether a business transaction is locally identified as an anomaly at step **380**. A business transaction may be locally identified as an anomaly by an agent that resides on an application or JVM and processes runtime data associated with the business transaction. The agent may identify the anomaly based on aggregated abnormal behavior for the business transaction, such as an increase in the rate of outliers for the business transaction. For example, if the business transaction has a higher rate of outliers in the last ten minutes than a learned baseline of outliers for the previous hour for the business transaction, the agent may identify the corresponding business transaction performance as an anomaly and trigger a diagnostic session to monitor the business transaction. Identifying a business transaction as an anomaly is discussed in more detail below with respect to the method of FIG. **4**.

If the business transaction is identified locally as an anomaly at step **380**, a diagnostic session is triggered and diagnostic data associated with the anomalous business transaction is collected at step **385**. Diagnostic data may be collected by sampling a thread call stack for the thread that is locally handling one or more requests that form the business transaction that triggered the diagnostic session. The agent may collect data for future occurrences of the business transaction. Outgoing calls associated with the monitored transaction may be monitored to initiate called applications to perform collect diagnostic data as part of the diagnostic session for the transaction. Collecting diagnostic data associated with an anomaly is discussed in more detail below with respect to FIG. **5**. After collecting diagnostic data, the method of FIG. **3**B ends. If the request is not identified locally as an anomaly, the method of FIG. **3**B ends.

FIG. **4** is a flow chart of an exemplary method for locally identifying an anomaly for a business transaction. The method of FIG. **4** may be performed by an agent, such as agent **134**, **144**, **164** or **154**, and may provide more detail for step **380** of the method of FIG. **3**B. Locally identifying an anomaly may begin with determining a business transaction performance baseline from collected runtime data at step **410**. The runtime data may include the time for an application or JVM to complete a business transaction. The performance baseline may be for a rate of outliers which occur for the business transaction for a period of time. The performance baseline may be determined for the particular machine, or virtual machine (such as a Java Virtual Machine) on which the agent is monitoring data.

A performance baseline may be determined automatically and continuously by an agent. The moving average may be associated with a particular window, such as one minute, ten minutes, or an hour, the time of day, day of the week, or other information to provide a context which more accurately describes the typical performance of the system being monitored. For example, baselines may be determined and updated for transactions occurring within a specific time range within a day, such as 11:00 AM to 2:00 PM. The baseline may be, for example, a moving average of the time to perform a request, the number of outliers occurring, or other data collected during the particular baseline window. For purposes of discussion, a baseline is discussed with respect to a rate of outliers occurring for a business transaction within a time window at a particular machine.

In some embodiments, a standard deviation may be automatically determined by the agent, controller, or other source and used to identify an anomaly. For example, a baseline may be determined from an average response time of one second for a particular transaction. The standard deviation may be 0.3 seconds. As such, a response time of 1.0-1.3 seconds may be an acceptable time for the business transaction to occur. A response time of 1.3-1.6 seconds may be categorized as "slow" for the particular request, and a response time of 1.6-1.9 seconds may be categorized as very slow and may be identified as an anomaly for the request. An anomaly may also be based on a number requests having a response time within a particular derivative range. For example, an anomaly may be triggered if 15% or more of requests have performed "slow", or if three or more instances of a request have performed "very slow."

The runtime data collected for current outliers is compared to the business transaction performance baseline at step **420** by the particular agent. For example, the number of outliers occurring for a business transaction in the time window is compared to the baseline of outlier occurrence for the business transaction.

An anomaly may be identified by the agent based on the comparison at step **430**. For example, if an agent detects that the number of outliers that occurred for a business transaction within a the past ten minutes is greater than the baseline outlier rate for the business transaction, the agent may identify an anomaly.

FIG. **5** is a flow chart of an exemplary method for collecting diagnostic data. The method of FIG. **5** may provide more detail for step **350** of the method of FIG. **3**A. A request global unique identifier (GUID) may be created and associated with the request at step **510**. The request GUID may be generated locally by an agent or remotely by a controller. When generated by a controller, the agent may create a temporary identifier for the anomaly, report the temporary identifier to the controller, and then receive the diagnostic session GUID to use subsequently to identify the anomaly.

A thread call stack may be sampled, stored and processed at step **520**. The thread assigned to handle a request may be sampled to determine what the thread is presently handling for the request. The thread call stack data received from the sampling may be stored for later processing for the particular distributed web transaction. Sampling and storing a thread call stack is discussed in more detail below with respect to the method at FIG. **6**A.

An outgoing application call may be modified with diagnostic tracking information at step **530**. When a call to an outside application is detected, the call may be modified with diagnostic information for the receiving application. The diagnostic information may include the diagnostic session GUID and other data. Modifying an outgoing application call with diagnostic tracking information is discussed in more detail with respect to the method at FIG. **7**.

A completed request is detected at step **540**. At the completion of the request, data for the request associated with the anomaly may be stored by the agent and eventually sent to a controller. The diagnostic session may be continued for a period of time specified in a corresponding diagnostic parameter for the agent.

FIG. **6**A is a flow chart of an exemplary method for sampling a thread. The method of FIG. **6**A may provide more detail for step **520** of the method of FIG. **5**. Thread identification information may be accessed at step **605**. The thread identification information may be accessed from a JVM or application server that manages the thread pool from which a thread was selected to handle a request associated with the anomaly.

An initial sampling rate for the thread may be set at step **610**. The initial sampling rate may be set to a default rate, for example a rate of every 10 milliseconds.

The current thread call stack is accessed at the set thread sampling rate at step **615**. Sampling the thread call stack may detect what the thread is currently doing. For example, sampling the thread call stack may reveal that the thread is currently processing a request, processing a call to another application, executing an EJB, or performing some other process. The thread call stack may be sampled and the sampled data may be stored locally by the agent sampling the stack.

After sampling of the thread call stack, the agent may determine whether the thread call stack data retrieved as a result of the sampling has changed at step **620**. The change is determined by the agent by comparing the most recent call stack data to the previous call stack data. A thread snapshot is updated at step **640** based on the most recent sampling. The snapshot indicates what the thread call stack has performed. An example of a call stack is discussed below with respect to the interface of FIG. **11**. The update may be based on calls, requests, or timelines identified from the sampling.

A thread snapshot is updated at step **625**. The thread snapshot is updated to indicate changes to the thread call stack. A determination is made at step **630** to determine if an event has been detected at step **630**. The event may be the expiration of a period of time (for example, based on thread sampling rate), the detection of a new request made by a thread, or some other event. If an event is detected, the thread call stack is sampled at step **635** and the method of FIG. **6**A continues to step **640**. If no event is detected, the method of FIG. **6**A continues to step **640**.

A determination is made at step **640** as to whether the thread has completed at step **640**. If the thread is complete, the method of FIG. **6**A ends. If the thread is not complete, a determination is made as to whether the thread sampling rate should be adjusted. In some embodiments, the sampling rate may be adjusted after a period of time, for example every two minutes. If the sampling rate is determined not to be adjusted at step **645**, the method of FIG. **6**A continues to step **615**. If the sampling rate is adjusted, the new sampling rate is set at step **650** and the method continues to step **615**. The sampling rate may be adjusted to save processing cycles and resources after a set period of time.

FIG. **6**B is an illustration of an exemplary thread call stack data representation over time. The method of FIG. **6**B indicates exemplary states of a thread call stack sampled at different times. Each state includes a snapshot of data in the call stack at the corresponding sampling times. For example, for a sampling at time of 0 milliseconds (ms), the call stack indicates that an initial request A is being executed. At a time of 10 ms, the thread call stack indicates that the thread is executing

a request to an application B. As such, it can be inferred that request A has made a call to application B. At a time of 20 ms, the thread call stack indicates that application B has called application C. At a time of 30 ms, there is no change in the stack.

At a time of 34 ms, a call to D may be detected. As a result, the thread call stack may be sampled as a result of detecting the call at a time of 34 ms. Hence, a thread call stack may be sampled in response to detecting a call in addition to periodically.

At a time of 40 ms in FIG. **6**B, the thread call stack indicates that application C is no longer present at the top of the stack. Rather, application D has been called by application B. The agent sampling the call stack may determine from this series of thread call stack data that application C executed for 20 ms and that application B called application D after calling application C. At a time of 50 ms, there is no change in the call stack.

At a time of 60 ms, application D has completed and application B has again called application C. An agent processing the thread call stack data may determine that application D executed for 20 ms, and application B called C a second time. The second call to application C may be represent a sequence of calls to application C (one at 20 ms sampling, and one at 60 ms sampling). The present technology may differentiate between each call to application C as part of the request. At 70 ms in time, application C has completed, corresponding to an execution of 10 milliseconds for the second call to application C. At a time of 80 ms, B has completed, corresponding to an execution time of 70 milliseconds for application B.

FIG. **7** is a flow chart of an exemplary method for modifying an application call. The method of FIG. **7** may provide more detail for step **530** of the method of FIG. **5** and may be performed by an agent located at an application or JVM that is calling the application.

First, an application call is detected at step **710**. The application call may be detected by sampling a thread call stack associated with the thread handling a request being monitored.

The application call recipient may be added to a call chain at step **720**. Once the call is detected at step **710**, information regarding the call can be accessed from the thread call stack, including the recipient of the detected call. The call recipient may be added to a call chain maintained in the thread being monitored. The call chain may include call sequence information if more than one call is made to a particular application as part of processing a request locally.

The call chain attribute and call sequence attribute may be added to the call header at step **730**. A diagnostic session GUID may be added to the call header at step **740**. An application receives the call with a diagnostic session GUID, and an agent at the receiving application detects the diagnostic session GUID. The agent on the receiving application may then monitor the thread processing the received call, associated collected data with the particular diagnostic session GUID, and report the data to a controller. The application call may then be sent with the modified call header to an application at step **750**.

FIG. **8** is a flow chart of an exemplary method for processing a received request. The method of FIG. **8** may be performed by an application which receives a request sent with a modified call header from an application collecting data as part of a diagnostics session. For example, the method of FIG. **8** describes how an application processes the received call that is originated by the application call of step **750**.

A request is received by the application at step **810**. An agent may detect a request GUID in the request header at step **820**. The request GUID may indicate an identifier for a diagnostic session currently underway for a distributed transaction that includes the particular request. The received request may be performed and monitored at step **830**. Runtime data, including diagnostic data, may be collected throughout processing of the request at step **840**. The request's completion is detected at step **850**, and a response to the received request is generated and transmitted to the requesting application at step **860**. Eventually, collected runtime data including diagnostic data and other data associated with the request may be reported to a controller at step **870**.

FIG. **9**A is a flow chart of an exemplary method for controller operation. The method of FIG. **9** may be performed by control **190**. Aggregated runtime data may be received from one or more agents by a controller at step **910**. The aggregated runtime data may include diagnostic data generated in response to triggering one or more diagnostic sessions.

A call chain may be constructed for each business transaction at step **920**. The call chain is constructed from the aggregated runtime data. For example, transactions may be pieced together based on request GUIDs and other data to build a call chain for each business transaction. Received diagnostic data for locally identified anomalies may be processed by the controller at step **930**. Processing the diagnostic data may include determining the response times for portions of a distributed business transaction as well as the transaction as a whole, identifying locally detected anomalies, and other processing. Baseline performance for a business transaction call chain is determined at step **940**. The baseline performance may be determined based on past performance for each business transaction and portions thereof, including for example each request that is made as part of a business transaction.

Selected agents associated with the applications and JVMs that perform the transaction associated with the anomaly are instructed to collect diagnostic data based on diagnostic parameters at step **950**. The diagnostic data may be collected as part of a diagnostic session already triggered by an agent (locally determined anomaly) or triggered by the controller. In some embodiments, the controller may determine whether the maximum number of diagnostic sessions is already reached, and if so may place the presently detected diagnostic session in a queue for execution as soon as a diagnostic session is available.

Diagnostic data is received from selected agents collecting data as part of the diagnostic session at step **960**. Performance data is generated from the collected diagnostic data received from one or more agents, and the performance data may be reported by the controller at step **970**. The performance data may be reported via one or more interfaces, for example through an interface discussed in more detail with respect to FIGS. **10**-**12**.

FIG. **9**B is a flow chart of an exemplary method for instructing agents by a controller. A determination is made as to whether any anomalies are identified by the controller based on baseline performance or received locally identified anomalies at step **975**. If no anomaly is detected, the method continues to step **985**. If an anomaly is detected, selected agents associated with the anomaly are instructed to collect diagnostic data based on diagnostic parameters at step **980**. The method then continues to step **985**.

A determination is made as to whether selected agents are identified to perform a diagnostic session per performance sampling at step **985**. If no agents are identified, the method

ends. If one or more agents are selected, the selected agents are instructed to collect diagnostic data based on the diagnostic parameters.

During a diagnostic session, deep diagnostic data may be retrieved for one or more distributed business transactions associated with a diagnostic session which are performed by one or more applications or JVMs. FIGS. **10-12** illustrate exemplary interfaces for displaying information associated with a diagnostic session.

FIG. **10** is an exemplary interface providing a transaction flow map. Interface **1000** in FIG. **10** includes a transaction flow map frame **1010**, a load information frame **1020**, average response time frame **1030**, incident description frame **1040**, and request summary frame. Transaction flow map frame **1010** provides a map of the applications or JVMs that comprise the distributed web transaction associated with a diagnostic session triggered by an anomaly. The upper portion of frame **1010** indicates the status of the anomaly request, the duration, the name of the business transaction, a triggering policy, a start time, an end time, and may include other additional data. The status of the request is "open," the duration is ongoing and has been ongoing for 10 minutes, the business transaction associated with the anomaly is a "checkout" transaction.

The transaction flow map **1010** includes an e-commerce service application, an inventory service application, an inbound inventory database, another inventory database, an order processing service application, and an orders database. The time spent at each application or database by the request is indicated in the flow map, as well as a percentage of the overall time the request spent at that application. Other information such as the type of request received between two applications is also shown to illustrate the relationships between the applications which perform the distributed application.

Load information frame **1020** indicates the load result for the particular request in a format of calls received per minute. The average response time frame indicates the average response time for the request over time. The incident description frame **1020** indicates a description of the incident associated with the anomaly. The request summary indicates the number of requests which fall into different categories, such as normal, slow, very slow, errors, and stalls. Other information, including recent request snapshots with call graphs and recent errors, may also be illustrated within a transaction flow map interface **1000**.

FIG. **11**A is an exemplary interface for providing a call graph. Interface **1100** includes a selection menu **1110** on the left side of the interface in which a call graph is selected. The main window **1120** of interface **1100** illustrates the call graph and in particular a hierarchical representation of calls made while executing the current request. An indication **1130** of an incident is indicated within the call graph. For each step in the call graph, the name of the application called, the time at which the application executed, external calls made by the application, and other details are illustrated in the call graph.

FIG. **11**B is an exemplary interface for providing more information for selected call within a call graph. In FIG. **11**B, a window appears in the in the lower right portion of the interface. The window provides more information for a selected portion of a call stack. The selected portion is a method titled "OrderServiceSDAP11Binding Stub:createOrder." The information provided in the window includes the web service name "Order Service", the operation name "createOrder", and the time, 10008 ms, taken to complete the call.

FIG. **12** is an exemplary interface for providing SQL call information. Interface **1200** of FIG. **12** indicates that SQL calls are indicated in a selection menu within the interface. The SQL call information is illustrated in a list of calls. An incident **1220** may be highlighted which indicates an incident associated with a particular SQL call. For each SQL call, information is illustrated such as the query type, the query, a count, the time of execution, the percentage time of the total transaction, the tier the call is received from, the tier the call is made to, and other data.

FIG. **13** illustrates an exemplary computing system **1300** that may be used to implement a computing device for use with the present technology. System **1300** of FIG. **13** may be implemented in the contexts of the likes of data store **130**, application server **120**, network server **130**, database **122**, and clients **150-160**. The computing system **1300** of FIG. **13** includes one or more processors **1310** and memory **1310**. Main memory **1310** stores, in part, instructions and data for execution by processor **1310**. Main memory **1310** can store the executable code when in operation. The system **1300** of FIG. **13** further includes a mass storage device **1330**, portable storage medium drive(s) **1340**, output devices **1350**, user input devices **1360**, a graphics display **1370**, and peripheral devices **1380**.

The components shown in FIG. **13** are depicted as being connected via a single bus **1390**. However, the components may be connected through one or more data transport means. For example, processor unit **1310** and main memory **1310** may be connected via a local microprocessor bus, and the mass storage device **1330**, peripheral device(s) **1380**, portable storage device **1340**, and display system **1370** may be connected via one or more input/output (I/O) buses.

Mass storage device **1330**, which may be implemented with a magnetic disk drive or an optical disk drive, is a non-volatile storage device for storing data and instructions for use by processor unit **1310**. Mass storage device **1330** can store the system software for implementing embodiments of the present invention for purposes of loading that software into main memory **1310**.

Portable storage device **1340** operates in conjunction with a portable non-volatile storage medium, such as a floppy disk, compact disk or Digital video disc, to input and output data and code to and from the computer system **1300** of FIG. **13**. The system software for implementing embodiments of the present invention may be stored on such a portable medium and input to the computer system **1300** via the portable storage device **1340**.

Input devices **1360** provide a portion of a user interface. Input devices **1360** may include an alpha-numeric keypad, such as a keyboard, for inputting alpha-numeric and other information, or a pointing device, such as a mouse, a trackball, stylus, or cursor direction keys. Additionally, the system **1300** as shown in FIG. **13** includes output devices **1350**. Examples of suitable output devices include speakers, printers, network interfaces, and monitors.

Display system **1370** may include a liquid crystal display (LCD) or other suitable display device. Display system **1370** receives textual and graphical information, and processes the information for output to the display device.

Peripherals **1380** may include any type of computer support device to add additional functionality to the computer system. For example, peripheral device(s) **1380** may include a modem or a router.

The components contained in the computer system **1300** of FIG. **13** are those typically found in computer systems that may be suitable for use with embodiments of the present invention and are intended to represent a broad category of such computer components that are well known in the art. Thus, the computer system **1300** of FIG. **13** can be a personal

computer, hand held computing device, telephone, mobile computing device, workstation, server, minicomputer, mainframe computer, or any other computing device. The computer can also include different bus configurations, networked platforms, multi-processor platforms, etc. Various operating systems can be used including Unix, Linux, Windows, Macintosh OS, Palm OS, and other suitable operating systems.

The foregoing detailed description of the technology herein has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the technology to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. The described embodiments were chosen in order to best explain the principles of the technology and its practical application to thereby enable others skilled in the art to best utilize the technology in various embodiments and with various modifications as are suited to the particular use contemplated. It is intended that the scope of the technology be defined by the claims appended hereto.

What is claimed is:

1. A method for sampling an application thread to monitor a request, comprising:

monitoring a request at a server, the request part of a distributed business transaction;

detecting a diagnostic event with respect to the processing of the request;

sampling a thread call stack associated with the request in response to detecting the diagnostic event;

updating a thread snapshot based on a state of the call stack over time with timing information, the state of the call stack retrieved from sampling the thread call stack based on the sampling, the timing information associated with particular call stack state, the snapshot including a hierarchical representation of calls performed during the request and detected by sampling the call stack; and

transmitting the thread snapshot and timing information to a remote server.

2. The method of claim **1**, wherein the diagnostic event includes an anomaly associated with the request.

3. The method of claim **1**, wherein the diagnostic event includes a request by a user to collect diagnostic data.

4. The method of claim **1**, further comprising:

detecting an outgoing call; and

sampling the thread call stack in response to detecting the outgoing call.

5. The method of claim **1**, wherein the outgoing call is detected by bytecode instrumentation.

6. The method of claim **1**, wherein the outgoing call is detected by code embedded into exit points within an application which makes the outgoing call.

7. The method of claim **1**, wherein the thread sampling rate is adjusted after a set period of time.

8. The method of claim **7**, wherein the sampling rate is adjusted based on the sampling results.

9. The method of claim **1**, wherein the sampling results in a plurality of stored call stack states that indicate one or more methods that are called at different times as part of handling the request.

10. The method of claim **9**, wherein a call graph of functions executed by an application thread is derived from the sampled call stack states.

11. A non-transitory computer readable storage medium having embodied thereon a program, the program being executable by a processor to perform a method for sampling an application thread to monitor a request, the method comprising:

monitoring a request at a server, the request part of a distributed business transaction;

detecting a diagnostic event with respect to the processing of the request;

sampling a thread call stack associated with the request in response to detecting the diagnostic event;

updating a thread snapshot based on a state of the call stack over time with timing information, the state of the call stack retrieved from sampling the thread call stack based on the sampling, the timing information associated with particular call stack state the snapshot including a hierarchical representation of calls performed during the request and detected by sampling the call stack; and

transmitting the thread snapshot and timing information to a remote server.

12. The non-transitory computer readable storage medium of claim **11**, wherein the diagnostic event includes an anomaly associated with the request.

13. The non-transitory computer readable storage medium of claim **11**, wherein the diagnostic event includes a request by a user to collect diagnostic data.

14. The non-transitory computer readable storage medium of claim **11**, the method further comprising:

detecting an outgoing call; and

sampling the thread call stack in response to detecting the outgoing call.

15. The non-transitory computer readable storage medium of claim **11**, wherein the outgoing call is detected by bytecode instrumentation.

16. The non-transitory computer readable storage medium of claim **11**, wherein the outgoing call is detected by code embedded into exit points within an application which makes the outgoing call.

17. The non-transitory computer readable storage medium of claim **11**, wherein the thread sampling rate is adjusted after a set period of time.

18. The non-transitory computer readable storage medium of claim **17**, wherein the sampling rate is adjusted based on the sampling results.

19. The non-transitory computer readable storage medium of claim **11**, wherein the sampling results in a plurality of stored call stack states that indicate one or more methods that are called at different times as part of the handling the request.

20. The non-transitory computer readable storage medium of claim **19**, wherein a call graph of functions executed by an application thread is derived from the sampled call stack states.

21. A system for monitoring a business transaction, comprising:

a first application server having memory; and

one or more modules stored in memory of the first application server and executable by a processor to monitor a request at a server, the request part of a distributed business transaction, detect a diagnostic event with respect to the processing of the request, sample thread call stack associated with the request in response to detecting the diagnostic event, update a thread snapshot based on a state of the call stack over time with timing information, the state of the call stack retrieved from sampling the thread call stack based on the sampling, the timing information associated with particular call stack state, the snapshot including a hierarchical representation of calls performed during the request and detected by sampling the call stack, and transmit the thread snapshot and timing information to a remote server.

22. The system of claim **21**, wherein the diagnostic event includes an anomaly associated with the request.

23. The system of claim 21, wherein the diagnostic event includes a request by a user to collect diagnostic data.

24. The system of claim 21, the modules further executable to detect an outgoing call and sample the thread call stack in response to detecting the outgoing call.

25. The system of claim 21, wherein the outgoing call is detected by bytecode instrumentation.

26. The system of claim 21, wherein the outgoing call is detected by code embedded into exit points within an application which makes the outgoing call.

27. The system of claim 21, wherein the thread sampling rate is adjusted after a set period of time.

28. The method of claim 27, wherein the sampling rate is adjusted based on the sampling results.

29. The system of claim 21, wherein the sampling results in a plurality of stored call stack states that indicate one or more methods that are called at different times as part of handling the request.

30. The method of claim 29, wherein a call graph of functions executed by an application thread is derived from the sampled call stack states.

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